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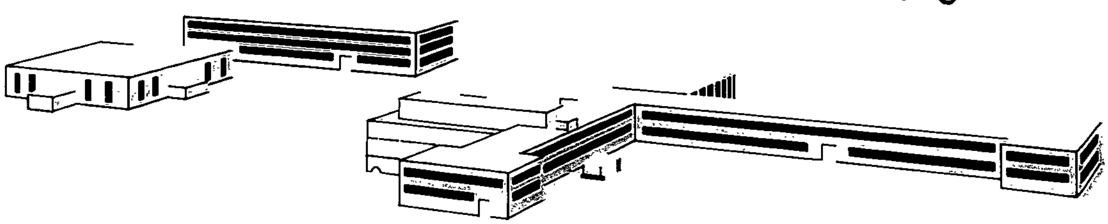
AN INFORMATION INDEXING APPROACH TO INFORMATION REQUIREMENT PROBLEMS



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ABSTRACT

The purpose of Contract NOnr 4441-(00) is to provide an empirical test of an information indexing approach to the assessment of user requirement, i.e., the information requirements placed upon intelligence and surveillance systems acting in support of command-control systems. This report, which draws heavily from work completed within a classified information (secret) context under Contract NOnr 3818-(00), presents the information indexing approach and contrasts it with two existing alternatives. Also included are illustrative examples of means by which each of the three approaches can be implemented in practice.

The method of testing the validity of critical assumptions underlying the information indexing approach will be discussed in a second report of the completed under the same contract. Briefly, the approach followed involves use of an experimental task which is a simplified analog of a number of military situations, e.g., an antisubmarine warfare (ASW) situation and an antiaircraft warfare situation (AAW). The context of the problem is such that it allows both objective and subjective determinations to be made of the worth of various types of information.

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I. DISCUSSION

A. STATEMENT OF PROCEDURE

The problem approached here is that of deriving "information requirements" of operational surveillance networks when such networks act in support of executive decision-making or command-control operations. In most cases these "requirements" can be interpreted as a set of constraints placed upon the supporting system by users or consumers, who are normally men; thus, both human factors and systems analysis problems are involved.

Such assessment problems have, in the past, been attacked by one or two possible approaches. The first of these may be termed a rational procedure by which available quantitative techniques such as information theory and dicision theory are applied directly to the problem. Thus, a requirement may be phased in terms of a stated number of bits of information or an expected value of x units. The second or unique solution approach attempts to identify those items of information whose presence is both necessary and sufficient for the implementation of an assigned mission or function. Usually requirements obtained by use of the unique solution procedure are specified in the form of lists, whose items may or may not be arrayed with respect to some variable, e.g., in order of their time priority or need. A third alternative, termed an information index approach, is presented with the aim of bridging the gap between the alternatives listed above. The indexing approach has as its basic precept the application of weightings which are derived from "importance" or utility values and the quantity associated with certain outputs of an information system. These outputs are, in the aggregate, indicative of system performance.

This is not an attempt to provide a completely exhaustive survey of approaches and methods of implementing these approaches. It simply attempts to point out differences in three approaches to the same general problem; approaches which, while they are related, are sufficiently disparate to yield widely different formats for results--formats which dictate important restrictions on the range of application of the results.

Before reviewing the major characteristics of each technique and the type of problems to which they are applicable, it is necessary to clarify the meaning of the term "requirement." Basically, when discussing "requirements," correlations are mentioned; i.e., the relationship between (a) certain types and amounts of information, and (b) decision adequacy. Therefore, the following definition can be offered: An information requirement is that amount and/or those types of information produced by the supporting operational network which allows the decision-maker to attain a proficiency level ϵ.

The above definition implicity assumes that a requirement imposed upon an operational surveillance network is directly related to an assessment of that network's output. Stated another way, it is possible to discuss information in terms of the difference it makes in command performance when it is present or absent. If this difference is measureable in some way, a value tag can be attached to that item of information and a requirement can be stated in terms of a set of items having a stated value. In short, what is "required" or "desired" is some level of executive performance including the antecedent conditions which permit its being reached.

In the discussions provided below, assessment is intimately involved in requirement specification. Therefore, there is considerable interest in how this assessment is made and how it serves to identify what the user needs in order to perform his job adequately.

B. THE MAJOR ALTERNATIVES

The first, or rational, approach can be applied to systems problems when considerable a priori knowledge is available concerning both the operational network and the executive decision-making system. For example, if information theory is to be used, it is necessary to catalogue the universe of information passing through the network into dimensions and to assign values on these dimensions which are within the message space. Then, the bit content of the information processing system can be measured under a wide range of conditions. However, even this step is only part of the problem because interest is primarily centered about the universe of decision alternatives and the way in which information supplied by the network serves to reduce uncertainty concerning the appropraite course of action to take. Thus, the executives' (or commanders') decision space must be similarly treated. The resulting correlation would then occur between bits of information in the message space and bits of information in the decision space*.

Decision theory can also be used to implement the rational approach. Here, investigators focus on the command or executive-output and measure its worth or value. Then, if the "decision rules" are known (that is if it is known what decisions are made in the light of certain information) the information input is manipulated over a wide range of conditions and a choice is made of that manipulation(or those manipulations) which reached the desired proficiency level or output level. Another related use of decision theory has been suggested by Schreiber (1961) whereby one selects those items of information which produce the largest variations in output utility.

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*The terms "message and decision spaces" as used here refer to the universe of possible information and the universe of possible decisions. Special concern is centered about the extent to which elements within the information and decision spaces can be described in analytical terms, viz., as coordinates in a multidimensional space. However, in order for this to occur, the basic variables involved and their interrelationships need to have been identified. Otherwise, the space cannot be dimensionalized. In addition, all elements need to have the property of being able to be measured in these dimensions. If these conditions are not met, the spaces can only be categorized into mutually exclusive sets and subsets according to some common underlying criterion such as message content.

The second technique mentioned, the unique solution approach, does not possess the metrical refinement gained through the use of decision theory or information theory. It is used primarily in situations where a priori knowledge is at a bare minimum -- such as the case in planning a new system. By means of survey or review methods, investigations follow what is basically a job analysis or job specification approach and attempt to identify information which "should be" transmitted by the network. Thus, an implicit assumption is usually made that the proficiency level desired has a fixed value -- or at least a fixed minimum value. The listed items can thereby serve as a stipulation of the conditions necessary and sufficient for reaching this value. Such an approach, which is well illustrated by the work of Vaughan, et al., (1960), has the disadvantage of not being readily applicable when the proficiency level desired is likely to vary or when the task is one of assessing alternative networks instead of stipulating what the networks should be handling. However, it is applicable to cases where the information units are not additive, that is where units of one type of information do not have some equivalence relation to units of another type of information -- a condition which precludes use of the rational approach.

The third, or information index approach, will be discussed most fully in this report. It is applicable to situations where the general nature of an operational network is known but where certain crucial aspects of the decision process remain unspecified. In such cases the different types of information available can only be categorized (sorted by content); dimensionalizing the information space is impossible. Also, decision rules are not at all fixed and are usually a matter of individual judgment (executive and command experience). Finally, the decision space is not dimensionalized either, because the executive may at a later date have new courses of action available to him.

In such situations, which are illustrated best by military intelligence networks, there is a need to evolve a quantitative assessment technique which can be used to evaluate the products of a series of proposed networks available now or in the future. Usually, such a goal can be accomplished by the use of a two stage process. First, users are asked to derive estimates of value for various types of information under a wide range of operating conditions. Then, these hypothetical utility values are checked against objective outputs from the executive system to insure that the utility values are valid in actual practice. An alternative to this sequence is one whereby the value index, which is in reality an intermediate criterion, is computed in a series of specific command situations and generalized later. In both cases, however, the approach is analogous to the one employed in multiple regression; an index value is expressed as a function of a series of variables each of which has some importance weighting. What makes the approach more complicated than traditional regression techniques is the fact that decision rules are so poorly specified. Therefore, some means of circumventing this obstacle has to be devised before characteristics of the information supplied can be related unambiguously to characteristics of the resulting decisions.

C. DISCUSSION OF THE ALTERNATIVES

As in the case with most classification schemes, separation of the three approaches outlined above is somewhat arbitrary. In reality, all of the three are interrelated to some extent. For example, the rational and information indexing approaches presuppose the existence of knowledge such as is obtained in the unique solution method, i. e., that the operational system available has been specified to a considerable extent. Furthermore, decision theory in some cases can be used to supplement the findings of the unique solution approach for the purpose of generating performance implications for these "necessary and sufficient" conditions even when the information space is not dimensionalized. Also, the use of a decision theory measure, utility, is incorporated into the information indexing approach in an attempt to allow quantification when decision rules do not exist. If they do exist, and if the information space can be catalogued only by message content, some combination of the first and third approaches evolves. In short, in addition to the use of each approach alone, combinations of approaches are possible.

Granting that there are complications arising in practice which can make it difficult to distinguish between the three basic techniques, enough important differences remain to make the above classification useful in systems analysis problems. These differences generally arise from two sources: (a) the nature of the problem under investigation and (b) the use to which the analysis will be put. These differences can be illustrated by presuming that an investigator begins his work by asking a series of questions, the answers to which determine what technique should be or can be used. These are listed below along with a discussion of what occurs when the answer is affirmative or negative.

1. Has the information passed through the operational network been specified and categorized?

a. If not, the primary problem is to accomplish this task by means of something similar to the unique solution approach. This technique presumes that is is possible to stipulate some desired level of command performance which can be used as a reference point when obtaining what the network should or would handle.* Usually, this approach terminates with the production of lists of things to be processed by the network.

These results can be used to evaluate the output of proposed systems (hence the system itself) in a checklist fashion. A further refinement can be added by weighting each item on the lists according to some criterion of importance (cf., Vaughan, et al., 1960). When this latter step is taken the unique solution approach begins to approximate results gained by use of the information indexing approach; however, there still is a difference remaining because if the desired command performance level is changed (the reference point mentioned above), there is no guarantee that the weightings will remain constant. Therefore, a number of iterations of the unique solution approach may be necessary.

Decision theory can also be used in conjunction with the unique solution approach to determine exactly what level of performance stems from the use of the proposed solution and what happens when the solution is only approximated or not used at all. Such a possibility is greatly enhanced if one has at hand the decision rules relating information input to resulting command choices. If such rules are not available, large scale simulations and/or system exercises are needed.

*While it is theoretically possible to derive a solution for a series of reference points at one time, practical limitations normally preclude such a possibility.

Thus, the unique solution approach is appropriate when the characteristics of the operational network are not well known. Its primary function is to identify the nature of the information that should or would be produced by the network. In addition, further refinements can be added to indicate what satisfaction of these requirements means in terms of command system performance. However, practical considerations normally preclude following this approach when a series of executive performance levels are to be studied.

b. If the condition specified above is satisfied, a second question is proposed.

2. To what extent can the information space and the decision space be measured and related?

a. If the decision and information spaces can only be sorted into mutually exclusive categories, while the decision rules relating the two remain vague, the information indexing approach is applicable. This technique, which is discussed at length below, assumes in its most general form that some type of equivalence relation exists between the various types of information. If this is not sufficiently compatible with reality, the unique solution technique outlined above can be followed for each type of information by itself. However, at best, the information indexing approach only approximates what would be obtained by use of the rational approach.

b. If the decision and information space can be dimensionalized and all items of information passing through the system have some value on each dimension, rational techniques can be used even when decision rules are not completely specified. However, the extent of manipulation required normally is too great for experiments involving command and executive personnel. Therefore, while the approach is applicable in a theoretical sense, practical considerations often eliminate it from consideration. When the decision rules are known, however, Monte Carlo techniques can be used to establish the necessary correspondence.

D. THE INFORMATION INDEXING APPROACH

Without attempting to escape blame for inadequacies of methodological rigor contained in succeeding portions of the paper, the authors wish to underscore the fact that this technique is not a device of their personal invention. Caldwell, et al., (1959) employed an analogous approach to the problem of evaluating the output of an Army intelligence system. However, the authors were not concerned with examining their approach as much as the results gained from the use of it; therefore, the present discussion overlaps only slightly. In addition, the technique draws heavily on utility measurement theory prepared by Davidson, Siegel, and Suppes (1955).

The key to evolving a method which promises to be more than an interesting mental exercise lies in the initial "structuring" of the problem -- primarily as it affects the identification of "units of information." Often operating systems have "natural" units present -- standardized messages for example -- which bear some unspecified relationship to an investigator's basic units of information. When the bit measure cannot be employed because of practical limitations, it is necessary to offer some substitute since "natural" units vary widely in the amounts of information contained. In such cases, it is often possible to use an approximation technique whereby one separates natural units into <u>items</u> of information.

The definition of an <u>item</u> must be adjusted to specific system requirements; therefore, it is difficult to define in general. In the case of surveillance systems, however, <u>an item can be defined as an observation made over a specific uninterrupted interval of time about a particular physical thing or an observable attribute or characteristic of that thing, the observation being made by a single sensing device (including man).</u> The criteria for deciding if one or two items are present therefore become as follows: (1) is the same sensor being used as a source of information? (2) is the object or characteristic being observed the same? and (3) is the time of observation the same? For convenience (which will become evident later) one additional criterion is suggested: (4) are the format and content of the information in the item constant?

At this point in the approach, the investigator has subdivided the information produced by an operational surveillance network -- or a portion of it -- over a given time interval into a set of messages correlated with the existing natural units. These messages can then be further subdivided into items in most cases; or, if he is indeed fortunate, the investigator can use the familiar <u>bit</u> measure and ignore the remainder of this approach which is based upon the assumption that the rational treatment is inapplicable.

If the above sequence can be accomplished in sufficiently precise form, it becomes comparatively simple to complete the approach. First, the items of information produced by the networks are examined with respect to their content, and classified into a set of mutually exclusive exhaustive categories. Each item is assigned to one and only one category. Now, if the utility of these content categories can then be measured by means of the methods of implementation to be explained later, the basic outline of the approach becomes evident.

For example, assume that a highly simplified case exists; one where the network contributes items of information which are highly valid. It is now possible to compute an index of worth of the network output being evaluated by the use of Equation 1.

$$B = \sum_{j=1}^{N} \sum_{i=1}^{n} W_i \; O_j \qquad (1)$$

where:

B. = the index of worth attributed to the output of a supporting operational system estimated on the basis of considering user requirements,

N = the number of mutually exclusive content areas into which items of information fall,

n = the number of items contained in a message,

W = the number of items belonging to the j^{th} content class contained in the i^{th} message,

a_j = the average value to the user of an item of information in the j^{th} class.

Thus, the above index is nothing more than a consideration of both the amount of information produced by a network and the worth, or value, of this information. It is an attempt to place a price tag on items of information produced by an operational network during a given time interval. The equation must be modified when the network produces information which is not always highly accurate. This can be accomplished by: (1) adding a validity factor ϕ_i, which can be defined as the estimated probability that the information in the i^{th} item is correct; and, (2) by adding a second summation which subtracts from the value of the correct information the loss in value accruing as a result of the incorrect information.

If the risk situation in which the decision-maker operates is symmetrical, i.e., if the magnitude of a gain associated with a particular information item equals the magnitude (disregarding sign) of the loss associated with that item being incorrect, the equation can be represented as follows:

$$I = \sum_{j=1}^{N} \sum_{i=1}^{n} W_i a_j \phi_j - \sum_{j=1}^{N} \sum_{i=1}^{n} W_i a_j (1 - \phi_j) \qquad (2)$$

where

I = the index of worth attributed to the output of a supporting operational system estimated on the basis of considering user requirements including validity.

ϕ_j = the validity attached to the j^{th} item.

W_i, a_j, n, and N are defined as above.

E. THE MEANING OF VALUE

It is apparent that the utility term in equation 1 and 2 is of particular significance. Ideally, this term would be determined by an objective cost analysis. For example, consider a military situation which is in doubt and may have one of two values, A or not A($\bar{A}$), with <u>a priori</u> probabilities of p(A), p($\bar{A}$). Since these states are mutually exclusive and collectively exhaustive, the following relationship exists

$$p(A) + 1(\bar{A}) = 1 \qquad (3)$$

Consideration must be given to errors of the two possible types, defined as follows:

Type 1 error = the presumption that the state is $\bar{A}$ when it is actually A.

Type 2 error = the presumption that the state is A when it is actually $\bar{A}$.

Assumptions: Assume that the costs* of the errors of the two types, C_1 and C_2, are known, or can be estimated, in terms of loss of military objectives, men, and equipment. This assumption is implicit in any decision rule for military activities. That the prior probabilities, $p(A)$ and $p(\bar{A})$, are known need not be stated as an assumption since one can act upon the premise that these constitute prior "degrees of belief" on the part of the military commander.

Decision Rules: There are two basic types of situations to be considered:

1. The a priori, no-information case where

   E_1, or the Expected cost of assuming "$\bar{A}$" = $C_1P(A)$, and E_2, or the Expected cost of assuming "A" = $C_2P(\bar{A})$.

Assume, in the following development, that the rational commander always follows the "expected value" strategy so as to minimize "expected cost." Hence, if $C_1P(A) > C_2P(\bar{A})$, then $E_1 > E_2$, so he will act upon the premise that $\bar{A}$ is the true state of affairs. If $E_2 > E_1$, he will act upon the premise that A is the true state of affairs.

*"Cost of an error" refers to net cost to the command system; e.g., if the true state of affairs is A and the commander acts upon the premise that it is $\bar{A}$, the cost of the error is the cost of the outcome under the wrong decision minus what the cost of the outcome would have been if he had made the right decision.

2. The *a posteriori,* partial information case:

Now assume that an item of information is provided to the commander, and that this item has two values, B and not B($\bar{B}$), during a given period of observation. For example B could represent the occurrence of a "blip" on a sensor display, and $\bar{B}$ its nonoccurrence, while state A could represent the presence of an enemy submarine, and $\bar{A}$ its absence.

Further, suppose that the event of B has a known probability of occurrence, p $(B/\bar{A})$, in the absence of the submarine, (due to the presence of sea life, oceanographic irregularities, etc.), and a greater probability, p(B/A), of occurrence in the presence of the submarine. Classical signal-detection theory adapts Bayes' Theorem, which states:

$$p(A/B) = \frac{p(A) \quad p(B/A)}{P(A)p(B/A) + P(\bar{A})\,p(B/\bar{A})} \tag{4}$$

This is the expression for the a *posteriori* or contingent probability of A, the presence of the submarine, which would represent the rational commander's degree of belief in the submarine's presence after having seen the sensor "blip," B.

Analogously, we derive

$$p(A/\bar{B}) = \frac{p(A) \quad p(\bar{B}/A)}{P(A) \;\; p(\bar{B}/A) + P(\bar{A}) \;\; p(\bar{B}/\bar{A})} \tag{5}$$

This represents the rational commander's *a posteriori* belief in the submarine's presence given that the sensor fails to yield a "positive" return, "B"; i.e., "$\bar{B}$" is the actual state of affairs.

In the case of no information, the expected cost (E_c) to the system was simply

$$E_c = \min. \begin{pmatrix} C_1 & p(A) \\ C_2 & p(\bar{A}) \end{pmatrix} \tag{6}$$

The expected cost to the system in the presence of the new item of information is

$$E_C' = p(B) \min \begin{Bmatrix} C_1 \; p(A/B) \\ C_2 \; p(\bar{A}/B) \end{Bmatrix} + \left[1 - p(B)\right] \min \begin{Bmatrix} C_1 \; p(A/\bar{B}) \\ C_2 \; p(\bar{A}/\bar{B}) \end{Bmatrix} \qquad (7)$$

Thus, the difference value, $E_C - E_C'$, represents the average or weighted worth of the information about the state of "B--not B" to the decision-maker. It corresponds to the a_j term in Equation (2).

The foregoing arguments can be readily generalized to cases where the military state of affairs, and/or the information given, may each have more than two possible values. While the illustrative example was drawn from original detection theory, the same principles would obviously apply to any item of relevant tactical or strategic information. However, it is apparent that a formulation of utility (a_j) in these terms requires the presence of considerable foreknowledge, a condition rarely satisfied in a wide range of intelligence situations. For this reason, less complete treatment needs to be adopted in certain cases using the modes of implementation described next.

F. METHODS OF IMPLEMENTATION

The preceding discussion considered three possible approaches which can be used to derive user requirements. Attention will now be focused upon an enumeration and description of the methods which are available to implement each approach. Each method of implementation is aimed at relating decisions to the information inputs of the command system. In the case of the unique solution approach, the decision is held constant while information input is varied in order to determine what is "needed" for the decision to be made. For the other two approaches, the information input is manipulated and observations are made regarding the command systems output in order to relate the two factors over a wide range of operating conditions. In either case, the "manipulations" may be made by:

1. the thought processes of experienced command personnel;
2. gaming or other simulations;
3. reconstruction of military engagements to determine what information was needed and how it was used;
4. experimental changes.

In determining information requirements in the field of intelligence, the following modes or methods of implementation seem applicable;

Method 1. Intuitive Judgment. Experienced military personnel who are considered experts in the action routines of the command system are asked, either in an interview situation or via a questionnaire, to deduce the consequence of the presence or lack of selected intelligence data or the importance of various intelligence items. This process is usually repeated for several situations.

Method 2. Gaming Techniques. This method covers a wide spectrum of activities ranging from the hand-played war games to pure simulation. In the hand-played war game, decisions are made by humans (as players or as umpires) and the outcomes of these decisions are hand-recorded and analyzed for specific situations of interest. In a machine assisted game some portions of the routine activities of the games (the recording and analysis) are handled by a computer while human players and umpires continue to participate as decision-makers. If a complete set of rules for players and umpires is devised the game can be completely machine operated. In this type of game the tactics and weapon parameters of both sides are computer performed, and the game is played by the computer with a readout indicating the results of the battle. Data derived from these techniques are usually evaluated against a criterion of threat or survival.

Method 3. A Posteriori Investigations. This method permits after the fact evaluation of specific information inputs to the command system as a function of the decisions made therefrom in cases where characteristics of both the information and the decision can be specified. There are several alternative ways in which to obtain data through this technique. Specifically, it is possible to evaluate the recorded messages received by command personnel during field exercises, or to determine the relationship of actual intelligence to successful decision-making in past battles through historical reconstructions. Judgments of value in this case would use the final outcome of the decisions as the criteria; the final outcome being determined from historical documents.

Method 4. Formal Experiments. This method allows for the development and control of specific parameters related to the actual situation of interest in order to state within a certain level of confidence what information is required by a decision-maker in that situation.

The following discussion presents: (1) the advantages and disadvantages associated with each mode; and, (2) illustrative examples from available literature on how these methods have been, or might be, adapted to the three alternative approaches.

G. SELECTIVE RESEARCH REVIEW.

The intuitive judgment method has been modified to serve various needs and is frequently described in the literature. Even though it permits gathering large amounts of data with a small expenditure of funds, the results obtained therefrom can be challenged on the grounds that they may be biased by the perceptions of the respondents. Equally as important is the consideration that there really is no guarantee that a respondent's insights will be analogous to "real life." Finally there is the problem of analyzing requirements in situations which may be so complex that they transcend human capability to extrapolate intuitively.

Caldwell et al., (1959) conducted one of the earliest large scale studies using the intuitive judgment method to implement an indexing of intelligence information. This work was concerned with evaluative analysis of Army tactical intelligence. The ultimate goal of the study was to obtain, through an intuitive evaluation of intelligence estimates from a large group of experienced Army officers, an algebraic model which would make possible an evaluation of the "worth" of various items of intelligence in relation to the value of an intelligence estimate. Caldwell reports that four questionnaires were used to elicit the responses of the officers from the Army Command and General Staff College. These questionnaires referred to three specific situation reports and were concerned with: (1) the kind of information an officer considered important in judging the intelligence estimate; (2) the kind of information an officer considered important in judging the courses of action presented; and, (3) the degree of confidence with which these judgments were made. Additional analyses were performed to obtain indications on whether there was a more simplified procedure for evaluating intelligence and surveillance systems. The model developed from the above study make it possible to reach some interesting conclusions regarding the expected "value" of intelligence on a particular kind of terrain in an offensive battle where conventional weapons were used by a specified tactical unit.

An example of this method being used to implement the unique solution approach occurs in a study by Bourne et al., (1961) which was directed toward determining user requirements for future information systems. This work was done within the context of information storage and retrieval; however, the results and methodology used are applicable and illustrative for our purpose. A survey technique, using personal interviews was employed to obtain responses from a specific user population in order to determine the importance of various "user requirements."* These user requirements were reduced to seven characteristics which were assigned weightings by a method of rankings. These characteristics are "generalizable" to a variety of information requirement problems and include: (1) minimum time to get relevant information to the user; (2) minimum amount of irrelevant information produced; (3) minimum amount of relevant information overlooked; (4) form in which the information was received; (5) assurances of completeness of coverage; (6) ease of communication between user and system; (7) indications of technical competence of each search product. This study resulted in the development of an ordinal list of importance for these seven characteristics which can be used to describe the optimum conditions for using the products of certain information systems.

Gaming techniques, or the second method of implementation, possess a somewhat higher degree of realism and objectivity than the intuitive judgment method described above. There are, however, disadvantages associated with each of the techniques covered under the broad category of Gaming Methods. For example, when hand played war games handle problems of significant detail, they become very complex, requiring a great amount of input data, and they

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*A distinction was made between "users" who come to the system seeking information and "operators" who actually work and maintain the system.

usually generate a great amount of output data. This type of game is usually slow, requiring a great deal of time from players and umpires as well as from those who prepare the rules and analyze the results. The machine-assisted game solves the problem of manual recording and analysis of the output data, but it does require a great deal of programming and "debugging" time and is still slow and costly on a per "battle" basis. Pure simulation reduces the time per game, but it is necessary to reduce all of the player and umpire decisions to a comphrehensive, all inclusive list of decision rules.

Research using this mode to implement a combination of the information indexing and rational approaches has been done by the staff of the Operations Research Office (ORO) of the Johns Hopkins University. Moss and Harris (1961) or ORO were the first to simulate an Army intelligence system in order to determine what the optimum mixture of pertinent, complete, timely, and accurate intelligence information really is. Since a large number of variables enter into an intelligence information simulation system and since it was possible to quantify (at least to a reasonable degree) these variables, it was decided that a computer simulation was preferable to a hand played or computer-aided simulation.

Briefly, the method employed by Moss and Harris for determining this optimum mixture via computer simulation was as follows:

1. An area of terrain was broken down into relatively small units in which various features such as altitude, height of foliage, traversability, etc. were noted and programmed into the computer. This minute breakdown was also made for the other secondary variables.

2. The locations of both the Red unit and the Blue unit were also programmed into the computer and certain capabilities were given to the Blue unit for acquiring intelligence information about the "enemy" (the Red unit).

3. The information about the Red unit was varied randomly but with control in terms of amount, pertinence, and accuracy. In other words, the information characteristics were varied separately; first the accuracy of the information was varied from 0.5 to 0.9 with pertinence held constant, then the pertinence

of the information was varied through the same range with the accuracy held constant. Each orientation could be considered one "game."

4. During each "game" at various intervals (which corresponded to a preset number of messages received by the Blue unit), the computer was stopped and a readout was called for which would give the Blue units' estimate of the location of the Red unit. Each readout gave a data point in terms of "ability to locate the enemy." The percentage of locations within 8 km of and including the area actually occupied by Red forces was tabulated, and any improvement in ability to located the Red unit accurately was graphically portrayed as a function of increased information. This ability to locate the Red unit was used as the criterion of effectiveness for the various combinations of the information characteristics.

Hantzes, Teunis and Harris also of ORO used this method to determine performance implication of information requirements for combat intelligence. This group interrogated experienced officers at regular intervals while they were actively engaged in a hand-played war game. This interrogation took the form of asking the officers the following questions in relation to a response (immediate action order) they had made to a specific message (intelligence input):

1. What orders are you giving as a result of the message?
2. Why are you giving them?
3. What units are involved?
4. When are the affected units to carry out the order?
5. Does this message affect your plans? If yes, how?

The intelligence messages were classified according to their attributes (e.g., source which collected the information, content and phase of game when it was received by the player). The immediate action orders of the players were also classified by their attributes (e.g., type of action called for, phase of game, and reasons for giving the order). A comparison was made relating responses of the officers to the attributes of the intelligence messages, specifically to (1) number of incoming messages, (2) reasons for information use and nonuse,

(3) the sources of collection, and (4) the content of messages. From these comparisons a list of important considerations related to information requirements which could be drawn from the analysis was derived.

There are many possibilities for using a computer simulation as the vehicle for deriving a measure-of-worth for various bits of intelligence. For example, it would be possible to make a computer simulation run similar to that of Moss and Harris whereby assignments of weighting would be given to each intelligence input on the basis of the data points provided by the graphic portrayal described above. It can be seen that after each bit of intelligence had been given a weighting of utility these weightings could be used to discriminate quantitatively among the outputs of surveillance systems which provide various types of intelligence to the commander.

A posteriori investigation has the advantage of being able to use the ultimate criterion measurement. e.g., the final outcome (success or defeat) in actual conflict. However, many times these investigations must rely upon written reports and when an attempt is made to relate the stated criterion to specific tactical decisions and the information required for these decisions, the problem of the reliability of human memory becomes acute. This is also complicated by the diversity of evaluations among different officers concerning the importance and value of certain intelligence information (and usually there is no way to measure this diversity).

This mode may be used to collect data from past exercises for the purpose of describing "what happened" and "why." In such a case an investigation of exercise data (messages) could derive information by a cross analysis of various parameters (e.g., sender, recipient, time lapse, mission, content, source, etc.).

Several historical reconstructions have been made which deal with certain aspects of intelligence system effectiveness. RAND (1956) reports such a study for the Fifth Army in Italy during World War II. This report was based on Allied and captured German documents. Its findings on the importance of various sources of battlefield intelligence and the amount of information available to the opposing armies are tentative, but they do indicate the potential value of historical research. Wohlsteitler, (1960), presents a dramatic picture of the intelligence information available preceding the attack on Pearl Harbor. This book, however, makes no effort to analyze the intelligence information required to avert or reduce the severity of the attack. An Army study of identifying strength and location also reconstructs historically the Second World War in the light of perceived enemy situations vs. actual enemy situations as recorded by enemy records.

Formal experiments have the advantage of permitting the experimenter to control and manipulate the specific variables (in this case intelligence information) with which he is concerned. It allows him to adhere rigorously to the formal rules of the scientific method and to perform sophisticated analysis of the results obtained by his manipulations. However, the experimenter may find it difficult to enlist the cooperation of competent subjects and to find an adequate criterion against which to measure the performance of the subjects once he has them.

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